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published in
Technological Forecasting and Social Change
2009

DOI (link to publisher)
10.1016/j.techfore.2008.03.017

document version
Peer reviewed version

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Technological Forecasting and Social Change, 76(2), 218-228

Published version: http://dx.doi.org/10.1016/j.techfore.2008.03.017

Link VU-DARE: http://hdl.handle.net/1871/23622

Published as: Berkhout, F., Angel, D., and Wieczorek, A., Asian development pathways and sustainable socio-technical regimes. *Technological Forecasting & Social Change* [Special Issue: Sustainability transitions in developing Asia: Are alternative development pathways likely? F. Berkhout, D. Angel, and A.J. Wieczorek (eds)] vol 76, no 2, 2009: 218-228.

Asian development pathways and sustainable socio-technical regimes

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Abstract

Rapid industrialisation in Asia is generating significant new demand for raw materials and pressure on local, regional and global environments. In the future these demands and pressures are expected to increase markedly. Informing these concerns are models of development that assume that economic growth follows a pattern leading to a convergence between the structure, growth and productivity of economies in the long run. In these models, the growth of industries, markets, technologies, capabilities and consumption behaviours are regarded as following patterns established in more advanced economies in a process of 'catch-up'. This paper argues for greater attention to the resource and environmental *quality* of development. It argues that by applying ideas from an emerging literature on 'systems innovation' it becomes possible to envisage the emergence of new, more resource-efficient socio-technical systems as the basis of more sustainable development pathways in developing Asia. Such sustainable socio-technical systems will emerge in the context of interaction between domestic and globalised markets, knowledge flows and governance. Key issues for a research agenda are set out.

Key words: innovation, socio-technical system, Asia, sustainability

Introduction: Convergence in models of development

Economic theories of development, going back to Rostow (1959) and Kuznets (1966), have tended to argue that once a process of industrialisation has begun in a country it follows a broadly-predictable pattern. Modern endogenous growth theories, emphasizing the role of knowledge and technology in economic growth, argue that, beyond a growth in total factor inputs, investments in productive capital and technological learning lead to rapid improvements in productivity, which in turn leads to wealth creation and economic growth. As applied to Asia, this model emphasizes the importance of knowledge and the accumulation of technological capabilities (Lall, 1987; Stiglitz, 2003). Even though the explanation for growth differs from a Rostovian stages model of development, the end point remains the same, with late-comer economies tending to be seen as convergent with those in advanced economies in their structure, productivity and slower rates of overall growth (Solow, 1956; Sala-I-Martin, 1996). This does not mean that there '…is one pattern of growth to which all economies conform...' (Lucas, 1988: 41), but that generally applicable mechanics can explain growth.

Economic growth is associated with structural change in the economy, with a shift from agriculture to industrial production, and rapid productivity improvements leading to growth in new industrial sectors and a growth in services. Traditional industries are modernised and new industries become established, with industries tending to be concentrated in highly energy, materials and water intensive sectors, such as steel, chemicals, petroleum and rubber and plastics. New consumption patterns emerge, affecting the demand - besides industrial goods - for food, energy, mobility, housing and other services.

To foster economic growth and structural change, to promote the process of urbanisation and to meet the demands of new consumers, major new socio-technical systems are put in place. The socio-technical systems concept draws on the idea of a technological regime (Nelson and Winter, 1982) as an embedded set of practices, skills, procedures, technologies, institutions and structures that order technological change and innovation, but expands the idea by including a broader range of institutional factors into the analysis, including the knowledge base, policy and governance, consumer behaviours and so on (Schot, Hoogma and Elzen, 1994; Rip and Kemp, 1998; and Geels, 2002).

In developing economies we observe the rapid growth and embedding of socio-technical systems. These include investments in energy systems; telecommunications; roads, mass transit and airport systems; housing, industrial and other buildings organised in urban systems; and water and sanitation systems, as well as food production and consumption systems. The specific nature of these socio-technical systems, the technologies they are based on, and the patterns of economic growth and consumption they foster, will have a profound influence on the resources and energy profile of the developing economy. In this paper we are interested in innovation theory that seeks to analyse the long-run emergence and change of socio-technical systems.

A significant proportion of emergent socio-technical systems will draw on international flows in knowledge, technology and investment. Such investments contribute, either directly and through the spillovers they generate in the rest of the economy, contribute a major component of economic growth in newly-industrialising countries (NICs) (Bose and Durkayastha, 1994; Sjöholm, 1997; Kathuria, 2002). This is what we would expect in models of knowledge, technology and capabilities diffusion through imitation and capital deepening, captured in the idea of 'catch up' (Syrquin and Chenery, 1989; Dowrick and Gemmell, 1991). The main point we want to emphasize here is that while much of the economic literature on processes of catch-up is concerned primarily with either changes in labour or total factor productivity, growth rates and per capita income, or with the growth of technological capabilities in leading industrial sectors, here we are more interested in the environmental *quality* of the socio-technical systems that form the underlying fabric of developing economies and societies. In particular, we want to emphasize the role of innovation and innovative capabilities in influencing the nature of critical socio-technical systems in rapidly developing Asian economies.

The principal argument of this paper is that the convergence of economic structures and growth rates - which plays such a central role in growth theories - does not imply that the emergence of socio-technical systems underpinning growth must also be convergent in terms of their technological and environmental quality. The specific resource and environmental composition of economic growth can be highly differentiated. In other words, late developing countries are not condemned to following the same high-resource-intensity and high-pollution trajectories of economic transformation of previous cases of industrialisations. But in order to understand the factors that might explain the emergence of alternative, more sustainable development pathways, we need to be able to account for the wide differentiation that we can already observe in the resource and environmental footprint of developing economies and sectors. By drawing on recent advances in the study of innovation in socio-technical systems, we propose mechanisms by which pathways of growth may deviate from convergence on a standard model of resource use and environmental profile along a predictable trajectory.

Among a range of others, three major factors will determine the resource and environmental profile of a country or sector's development: resource endowments; governance; and the accumulation of technological and innovative capabilities. In this paper we are especially concerned with the third of these factors as it affects the emergence and shaping of socio-technical regimes. In the remainder of this paper we first review the literature on economic development and the environment, and in particular the debate about the Environmental Kuznets Curve (EKC). We then outline recent work on systems innovation, and assess the causes and characteristics of economic development in Asian contexts, paying special attention to the assimilation of knowledge and technologies in developing economies. We conclude by drawing together the main arguments of the paper, with the aim of stimulating debate and the articulation of a new research agenda.

Economic development and the environment

Like classical theories of growth, theories of the relationship between economic development and its environmental impacts (the income-environment relationship, Islam, 1997) also assume a standard model of change. The basic economic argument of much of this literature is that as income grows, the marginal utility of consumption is constant or falling, but the marginal disutility of pollution grows and the marginal costs of abatement fall. At some point disutility outweighs the costs of pollution prevention and countries begin investing in improving environmental quality. A number of reasons given for this point of inflexion – stylised in the environmental Kuznets curve (EKC) - including increased awareness about the costs of poor environmental quality, and the falling relative price of less polluting and clean-up technologies.

FIGURE 1 ABOUT HERE

Whether or not all countries follow the same path has been widely disputed: Dasgupta et al. (2002) and Tisdell (2001) argue that there are a range of trajectories (see Figure 2); and Marcotullio et al. (2005) argue that developing countries experience changes in pollution intensity sooner, faster and more simultaneously than industrialised countries before them (see Figure 3). In any case, there has been much debate about the validity of the EKC (Copeland and Taylor, 2004; Stern, 2004), with many analysts arguing that no simple relationship exists between income and environment.

FIGURE 2 ABOUT HERE

FIGURE 3 ABOUT HERE

An important development of the EKC hypothesis has been to associate different types of environmental problems with different levels of per capita income (Shafik and Bandyopadhyay, 1992). That is, local environmental quality problems associated with direct impacts on health and amenity (so-called 'brown' problems like drinking water contaminated with faecal coliform) are resolved first primarily through investments in new urban infrastructures. Local and regional environmental problems linked with economic and urban growth ('grey' problems like urban smog) are resolved at a later stage through environmental policy measures, while regional and global environmental problems associated with higher levels of consumption ('green' problems like domestic waste generation and greenhouse gas emissions) are not de-linked from income at any stage.

We can see a mirror of the 'growth convergence hypothesis' in the formulation of the EKC. The EKC also suggests that development follows a fixed sequence of stages in resource-intensity, environmental quality and investment in environmental management and policy. At each successive stage of development – associated with different levels of per capita income – a more or less predictable set of patterns of environmental problems emerges with characteristic responses through investment and policy which address emerging public awareness through new governance arrangements. There are questions about whether each country follows the same pathway, but the assumption that there is a link between environmental quality and income is widely-held. If this link is not a simple one, as many critics of the EKC suggest, then the challenge is to explain the variance.

But a serious weakness of critiques of the EKC is that, beyond introducing new non-income factors into their analysis, they do not offer an alternative analysis of processes of economic or technological change that may explain the absence of a U-shaped relationship, or the differing income levels at which they may be observed in different contexts. For instance, recent work on EKC has sought to include proper environmental governance to explain the variance that is found in econometric studies (Dasgupta et al, 2006). This follows a tradition in which political scientists have emphasized the importance of environmental policy in determining environmental quality also in development countries (Sonnenfeld and Mol, 2006). This remains what might be termed a 'thin' analysis of the environmental *quality* of economic and technological change.

An alternative *systems innovation* framework would argue that we should look not only the management of environmental problems arising from conventional development pathways, but to go beyond this and to investigate the economic and social conditions under which qualitatively different development pathways may arise. This perspective emphasizes the structural, technological and behavioural characteristics of development. If the pattern of resource- or pollution-intensity is to a large extent determined by underlying economic structure and the socio-technical systems that support this structure, and if these are only indirectly related to per capita income and growth rates, then we need an analysis of the quality of change in these systems to explain trajectories and patterns of pollution and resource-use.

Analysing stability and change in socio-technical systems: perspectives from innovation studies

Economic development and technical change have long been associated with environmental degradation. Since the emergence of modern environmentalism in the 1960s and 1970s, industrialized countries have made great progress at mitigating many pollution problems through better governance and investments in new technologies and practices. But even as 'brown' and 'grey' environmental problems were successfully addressed, new environmental problems were generated primarily through the the growing scale and scope of economic activity. Over time there have been systematic trends in the way environmental problems become manifest – shifting from smaller to larger spatial scale, from acute short-term problems to chronic longer-term or cumulative ones, and from discrete issues typically involving one source of environmental stress and one primary form of effect, to linked syndromes of environmental degradation involving multiple sources and multiple effects (Kates et al., 1990)

Addressing these syndromes of degradation requires progressively more far-reaching changes in production and consumption systems. While early policy responses were focused on the innovation and diffusion of so-called 'end of pipe' technologies in conventional industrial products and processes, progressively more attention has been given to the wholesale substitution of conventional products and processes with alternatives with radically-smaller resource and environmental footprints (Graedel, 1994), as distinct to the adaptation of conventional technologies. But the substitution of technologies across production and consumption systems is typically not a question of replacing one component with another. Wider, more disruptive changes usually result in the structure and relationships between technologies and actors. Under such conditions it is appropriate to speak of the innovation of systems, or 'systems innovation' for short, since we are concerned not just with the generation of new products and processes, but also with economic, social and institutional processes that lead to radically-new configurations of technologies within systems. Attention to the substitution of product and process technologies has therefore led an interest in the innovation of systems (Berkhout, 2002).

The systems innovation literature seeks to address this problem by analysing the emergence and dynamics of large-scale, long-term socio-technical transformations (Kemp, Schot and Hoogma, 1998). These changes are viewed as evolutionary processes, including technological, as well as economic, institutional and social dimensions – hence the designation *socio-technical system*. Within a socio-technical system new and conventional technologies and practices will be configured and reconfigured by a range of new and existing actors, operating according to new and existing rules, interests and commitments. This is likely to be a messy and uneven process, much of it cumulative and incremental, but with occasional discontinuities, leading over the longer run to the reordering or substitution of one socio-technical system by another.

Emphasis is placed on the *co-evolution* of technical, economic, institutional, cognitive and behavioural changes across three different levels (the niche, the regime and the landscape) of a socio-technical system. Within this system, the socio-technical regime represents the central ordering element, mediating between novelty introduced, in part, through experiments in niches, and the structure imposed by the institutional and economic landscape in which the regime operates (Geels, 2002; Smith et al., 2005). In common with evolutionary theories of innovation (Nelson and Winter, 1982; Dosi, 1988), the creation of socio-technical variety and its selection within the context of markets and other institutions stands at the core of the analysis. What differentiates a systems innovation approach is the proposition that processes of variety creation and selection operate not just at the level of the individual technology and firm, but also at the level of the socio-technical regime. That is, just as firms face competitive pressures to innovate, so socio-technical regimes face selection pressures from alternative regimes, with the articulation of these pressures and the capacity to adapt to them being decisive for the survival of one regime relative to the alternatives.

Socio-technical regimes are relatively stable configurations of institutions, techniques and artefacts – as well as rules, practices and networks – that determine the 'normal' development and use of technologies (Rip and Kemp, 1998). They fulfil socially-valued functions which they also help to constitute. Socio-technical regimes therefore embody strongly-held convictions and interests concerning technological learning and innovation, among both producers and users. Modern, industrialised agriculture, for example, has evolved along a trajectory in which increased factor productivity has been the goal, with the greatest gains being achieved through investments in mechanisation and the integration of supply chains. Increased inputs of energy and chemicals have boosted agricultural output per unit of labour and capital. But alternative conceptualisations of agricultural regimes, stressing the harnessing of local ecological capacities have co-existed with the industrialised model, even if they have struggled to gain widespread acceptance. Organic farming focuses on output per unit of land area, usually favouring mixed farms, and is concerned with nurturing soil fertility through the relatively closed cycling of nutrients. The organic alternative was originally advocated by a small group of dissenting campaigners and scientists around the time that the principles of industrialised agriculture were being embedded in government policy in the US and Europe in the 1930s and 1940s (Conford, 2001). It is only now beginning to reach the status of a substantial niche socio-technical activity (in the sense that there is a robust network of actors, institutions and practices supporting the organic approach to agriculture).

Regimes exist across different empirical scales (Smith et al., 2005). At a relatively high level of aggregation, the electricity-generating regime is dominated by rules and practices relating to centralised, large scale (usually thermal) power technology and high voltage alternating current grid infrastructures. The respective responsibilities of producers (such as, supply security) and consumers (such as, the right to supply as well as consume), the regulation of pricing and safety, the nature of electricity markets, the policy regime with regards to alternative supply and demand technologies, and so on, have been built around and reinforce specific patterns of energy use in developed and developing economies. At a lower level of aggregation, the electricity generating regime spans a variety of nested subordinate regimes representing alternative technologies that supply and use energy, such as the coal and gas-fired steam turbines, the nuclear fuel cycle and hydroelectric dams. They nevertheless represent well-articulated configurations of technology and practice with well-defined actor networks and institutional contexts.

Regimes differ from socio-technical niches, which are not fully articulated and stable socio-technical configurations (Raven, 2006). Niches are defined as: '…protected spaces for the development and use of promising technologies by means of experimentation, with the aim of 1) learning about the desirability of the new technology, and 2) enhancing the further development and the rate of application of the new technology' (Kemp et al., 1998:186). Niches stand outside (and initially often in opposition to) conventional regimes and have influence on them in a number of potential ways: by demonstrating alternative ways of providing goods and services; by creating powerful and resourced new actor networks; by generating shared expectations about the promise of a new technology; and by producing a competitive models of alternative regimes. Smith (2007), investigating the influence of eco-housing and organic food niches on conventional house-building and food production in the UK, argues that a series of dynamic interactions – which he terms translations - occur between niches and regimes. While niches provide a demonstration of how conventional regimes could be reconfigured, their subsequent influence depends on an ability to articulate with incumbent regime dimensions. So, for instance, for organic food to be distributed by major retailers, organic ingredients had to fit processing and marketing requirements of the large supermarkets. While organic food has became widely diffused, this has not altered mainstream food practices significantly.

Niches that become stabilised, coherent and successful can come to represent regimes, and indeed given the nested nature of regimes, the distinction between a consolidated niches and an emergent regimes will be difficult to draw. So for instance in renewable generated electricity, a regime has emerged globally that is dominated by 3-bladed, horizontal axis megawatt-scale wind turbines operating in grid-connected clusters and supported through public policy (Gipe, 1995). Recent developments to promote distributed solar energy utilisation through PV installations integrated into the structure of buildings is another example of a new and distinct pattern, nested within the wider developing 'distributed renewables' regime, itself a relatively small part of encompassing national and regional electricity supply regimes. Under conditions where incumbent regimes face major economic or other pressures, consolidated niches may come to transform or replace them. These pressures on the incumbent regime may be intrinsic to the regime, in the sense of a serious social or technical problem that is difficult to resolve (the problem of nuclear waste management in an example in the nuclear power industry); or pressures may arise from the competition of emergent niche alternatives; or pressures may arise from the macro-context (the landscape) of the regime.

Socio-technical landscapes are the broad political, economic and institutional contexts within which socio-technical regimes are situated and evolve: '…background variables such as the material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macro economy, demography and the natural environment which channel transition processes and change themselves slowly in an autonomous way' (Kemp and Rotmans, 2001:7)'. Landscapes may be regarded as selection environments for regimes, defining the conditions under which they operate and exposing them to new pressures once these conditions change. So, for instance, major changes such as the deregulation of utility industries in many countries exposed incumbent electricity supply technologies to new pressures, so providing opportunities for alternative technologies to emerge rapidly from niches where they had previously been operating. The emergence of combined-cycle gas turbine (CCGT) technologies in the 1990s as a major electricity supply technology is a classic example (Joskow, 1998).

A variety of perspectives on change in socio-technical regimes have developed (Smith et al., 2005; Geels and Schot, 2007), each with a different analysis of the sources and conditions for such change. These include approaches (Geels, 2002) that emphasize the role of experimentation in niches with new technologies by emergent networks of actors - including innovators and users, approaches emphasizing the importance of innovation systems that support specific regimes (Jacobsson and Johnson, 2000; Hekkert et al., 2007), and approaches that emphasize the role of landscape changes in creating the conditions for change (Berkhout et al., 2004). All seek to deal with the tension between on the one hand the necessary processes of ordering, stabilisation and path dependency in socio-technical regimes, and on the other the generation of variety and disordering in processes of system innovation.

The question being asked is how powerful, well-articulated and stable socio-technical regimes regarded as unsustainable (fossil fuel-based energy systems for instance) can come to be modified or replaced by more sustainable alternatives over the longer term. As with processes of economic development, transitions towards more sustainable patterns of economic change are seen as transformations involving structural change over decadal time periods. Path dependency and lock-in are overcome because dominant socio-technical trajectories suffer from technical, environmental or social weaknesses that prove unmanageable in the context of dominant designs and systems, and because viable alternatives that offer relative advantages become available. Such advantages in terms of performance, cost and institutional embeddedness become manifest and recognised by actors, enabling innovation systems at the national and regional level (Freeman, 1995). Path creation is therefore the result of an interaction between experimentation and entrepreneurial activity in niches, perceived limits of incumbent socio-technical regimes, and economic and institutional factors in the broader 'landscape'.

What lessons can we draw from the systems innovation literature that is relevant for the broader process of economic development in Asia and other regions of the world? The first is that we are concerned with the emergence and substitution of new economic sectors and socio-technical regimes, that is with the meso-scale structure of production and consumption systems. Second, we pay special attention to the role of knowledge, technology and learning in these broad transformations, but always within an institutional context. Third, emergent regimes are not a direct transfer of models from more advanced countries, but are the result of processes of active configuration in which innovative and entrepreneurial activity, as well as institutions and governance have a profound influence on the rate and direction of change. Fourth, at any given point there are a wide variety of alternative regimes that might be constructed, with the final outcome often highly uncertain. Transformative economic and institutional change is already underway in Asia, so that countries in the region represent an excellent place to observe multiple socio-technical transitions. Moreover, whereas socio-technical transitions towards sustainability in industrialised countries need to overcome economic and political commitments to incumbent socio-technical regimes, this is much less the case in developing country contexts. How might the current period of industrial transformation in Asia be harnessed towards more sustainable development pathways? Below we review some key features of development in the south and east Asian region as a basis for drawing some conclusions about the links between systems innovation and growth theory.

Economic growth and urban-industrial transitions in developing Asia

Economic growth in developing Asia, and especially about the newly industrializing countries (NICs) of south and east Asia has been built on a process of industrialisation. Between 1971 and 2002, industrial value added in the East Asia NICs grew by an annual average of 8.7%, as compared to 1.6% in the Middle East and North Africa, 5.7% in South Asia, 3.6% in sub-Saharan Africa, and 3.3% in Latin America and the Caribbean. The share of industrial production in GDP roughly doubled within the Asian NICs from 21.9% in 1971 to 45.6% in 2002 (World Bank, 2004). Rapid industrial growth has been accompanied by urban and infrastructural developments on an unprecedented scale. Between 1970 and 2000 the urban population in developing Asia grew from about 485 million to 1,365 million people. The percentage of the region's population living in cities increased from 22.7% in 1970 to 37.1% in 2000, and this profound rural-urban transition is still underway. The urban population of developing Asia will double in size again between 2000 and 2030, adding approximately 1,300 million additional urban residents (UN, 2006). Within a generation, industrializing Asia will be predominantly urban.

Causes of growth in Asia

The causes of economic growth and change in Asia have been widely-studied. Nelson and Pack (1999) argue that there are broadly two traditions of analysis: the assimilation and accumulation theories. The former argues that '...learning and technology absorption, large investments in physical and human capital, and forceful entrepeneurship together resulted in a growing modern sector and diminishing craft sector (op cit., 423). In contrast, the latter holds that massive investments in physical and human capital alone are sufficient to explain growth. This tradition pays no special attention to entrepeneurship, innovation and learning. Following Nelson and Pack and others (Hobday, 1995; Kim, 1997), we adopt the view that these are important factors in explaining industrialisation and growth in Asia, with Government policy playing an important role in inducing an orientation towards exports of manufactured goods. By competing in world markets, manufacturers learned to perform to world standards, while becoming embedded in global production networks that involve contracting to American or Japanese firms who demanded high standards and provided assistance in achieving them (Ernst and Kim, 2002). Critical to learning and capability development was the broader institutional context (the system of innovation) within which firms they operate.[1] Specifically, many of the most successful Asian economies (Japan, Korea, Taiwan, Singapore) have pursued corporatist policies with explicit industrial policies with strong relationships between the state, the private sector and civil society aimed at rapid technological and industrial catch up.[2]

These important institutional and political differences point to other significant differences in the causes of growth across Asian countries. Booth (1999) compares the fast-growing economies of South-East Asia (Indonesia, Thailand, Malaysia) with those of North-East Asia (Japan, Taiwan, South Korea, China) and argue that growth in North East Asia is characterised by a number of factors: i) investment in human and physical capital, with high education levels prior to growth; ii) strong incentives for saving and domestic investment, with relatively lower contributions of FDI (under 10% in of total capital investment); iii) egalitarian distribution of income and assets prior to growth; iv) rapid export growth; and v) an insulated bureaucracy relatively free from pressure from rent-seekers and playing an active role in creating and fixing market institutions, promoting exports, encouraging saving. By contrast, South East Asian countries have been characterised by: i) dependence on natural resources, squeezing out profitable investment in other sectors and raising prices; ii) education and income distribution inequities; iii) a less important role of Government, with growth attributed more to MNCs investing in the region to take advantage of lower

[1] A system of innovation is '…that set of institutions which…contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process.' (Metcalfe, 1995). This may be equated with the landscape level of institutions of the socio-technical system.

[2] See Mike Rock (this issue) on the developmental state.

costs. Such historical differences have had a marked impact on the timing, pattern and rate of economic growth, but we would also expect them to have had an impact on the development of socio-technical regimes, and by extension on the environmental quality of development.

The context of globalisation

Whatever the economic, political, institutional and cultural antecedents have been in different Asian countries, it is evident that economic growth has been to a great extent influenced by the way in which economies are integrated into global markets and production networks. These linkages have been in terms of capital, technology and knowledge flows, initially primarily to developing economies, and the trade in goods and services. The absolute growth in net capital flows to developing Asia has been significant, with inward FDI flows as a proportion of gross fixed capital formation rising from 3-4% in the early 1970s to levels of 10-12% over the past decade (UNCTAD, 2007). Merchandize exports as a percentage of GDP have also grown over four decades and are now at an historical high (World Bank 2002). The export/GDP ratio is high and growing among many of the newly industrializing economies in Asia, compared to other developing countries, with these countries counted among the "new globalisers" that are becoming more connected to the global economy through trade and investment and have been growing rapidly. Much of this has been based on a dramatic shift toward manufactures as the dominant form of exports (rather than primary commodities).

Many economies in developing Asia, including China, Singapore, Malaysia, Indonesia and Thailand, have emerged as competitive sites of production for manufactured goods, despite their marked institutional and societal differences. As we have already argued a critical factor has been the emergence of a dynamic process of technological capabilities building. Further, it is now clear that it is not just the *level* of involvement in production and export of manufacturing goods that are defining features of developing Asian country engagement in globalization – it is also the *form* that this is taking. Here the role of transnational companies and global production networks in fostering knowledge and capacity building is particularly evident (Lall, 1992; Stiglitz, 1996).

In sum, the integration of south and east Asia into the global economy today has been marked by: massive investments in human and physical capital; high levels of foreign direct investment in select countries; policy regimes inducing an export orientation among domestic firms; and unprecedented levels of merchandize goods exports based on 'climbing the ladder' of technological capabilities building. For the purposes of our general argument here, we want to stress three features of these development processes. First, the assimilation of new technologies entails learning and innovation. The transfer of knowledge therefore always entails its translation to local conditions and circumstances, and therefore the accumulation of innovative capabilities. Such capabilities provide the basis for innovative and entrepreneurial activity by domestic and transnational firms and other actors to influence the quality of development long before a sector or a country has reached an international technological frontier. Second, industrialisation in many parts of developing Asia has been influenced to an unprecedented extent by the requirements placed on domestic manufacturers operating in global production networks and by global finance. This has meant not only that learning and investment have been more aligned with international environmental performance standards, but that the resource and environmental management capabilities have been assimilated early in production systems. Third, the institutions and actor configurations implied by the developmental state (Evans, 1995) in some Asian countries (China, Taiwan, Korea and Singapore) and their influence on economic and social development, provides a powerful institutional setting from which to shape more sustainable development pathways. An example of this is China's most recent 5-year plan, a central theme of which is the 'Resource-Efficient and Environment-Friendly (REEF) Society'(Wang et al. 2006). Fourth, through their export-orientation and through trade in basic commodities, many Asian countries are facing economic and competitiveness pressures to improve both labour and resource productivity at earlier stages of growth. Developing an energy system at $100 per barrel produces quite different results that at $20 per barrel.

Drawing together the strands: linking development and sustainability transitions

The aim of this paper has been to show that economic development in Asia can be analysed as a process of systems innovation. A key feature of economic development is the emergence of new socio-technical systems, replacing or radically altering traditional and early-modern systems in key sectors, including energy, transport, agriculture and food, water and urban development. These new systems emerge through the interplay between new knowledge and practices on the one hand, and the prevailing institutional and social contexts on the other. The central elements of these systems – socio-technical regimes – are the embedded outcomes of processes occurring at different levels of the system, including innovation in niches and adjustment of landscapes (systems of innovation). Although such theoretical insights were devised to explain socio-technical change in relatively stable contexts in developed countries, they are also salient to much more economically-dynamic contexts in rapidly developing countries.

But analysing system innovation in developing countries requires much clearer attention to the international context in which it is taking place. Much of the knowledge and many of the technologies that underpin emerging socio-technical regimes in developing countries are diffused from technologically-advanced countries. It is clear that there is great variety in the nature, scope and quality of these regimes in different countries and regions and this is partly explained by the capacity of a variety of actors (including firms, governments, civil society and consumers) to assimilate and adapt these technologies to create new socio-technical configurations. And we argue that these regimes will have a marked influence on the resource and environmental footprint of a country, region or sector. Development pathways may have radically-different resource and environmental quality if the interplay between innovation – whether generated through local or global networks – and institutions is organised so as to search for and incentivise more sustainable configurations, while discouraging the alternative.

Just as the conceptual frame of systems innovation is relevant to research on economic development, so development processes in Asia are relevant to systems innovation research. For development research this means that processes of capital and capabilities accumulation and diffusion need to be specified in terms of the role they play in the creation of socio-technical regimes and on how they influence the environmental quality of those systems. For systems innovation research, Asian development contexts can be seen as representing a series of large-scale, contemporary and fast-moving processes of socio-technical systems innovation. Empirically, as well as analytically, these diverse contexts therefore represent excellent sites for systems innovation research.

Besides these general aims, the paper also makes the following arguments.

Recognising the scale and momentum of Asian development: It is widely appreciated that the scale of economic, social, political and environmental transformation now occurring in developing Asia is unprecedented in human history. It is also widely believed that these urban-industrial changes are critical to key global resource and sustainability problems, including the global demand for raw materials, global agricultural production, global fisheries, deforestation and global climate change (Economy, 2004). China became, in 2006, the second largest emitter of CO_2 and is likely to become the largest global polluter within the next 10 years (MNP, 2007). Total energy sector CO_2 emissions in China, India and the rest of developing Asia are projected at about 5500 Gt for 2010, compared to 12,000 Gt for the OECD as a whole (ADB, 2006). Chinese road transport emissions alone are due to triple between 2004 and 2030 (IEA, 2007). On the whole, projections about the future are simple extrapolations of recent trends. But the patterns of consumption and pollution they project are far from inevitable. Supply constraints, higher prices and strategic competition for resources will all have major impacts on the supply of and demand for resources. The nature and composition of emerging socio-technical systems will also have a major influence. Understanding how innovation in emergent socio-technical regimes influences the demand for resources and impacts on environmental services is of vital global scientific and policy relevance.

Observing the rapid emergence of new socio-technical systems: Economic analysis of development emphasizes the role of the accumulation and assimilation of new knowledge and capabilities in rapidly-growing leading industrial sectors. We emphasize instead the interplay of innovative activity and institutional contexts in the reconfiguration of socio-technical regimes in key sectors and settings. While the flow of knowledge and capabilities from more advanced countries through foreign direct investment and global production networks may be important, processes of knowledge and capability diffusion are never simple translations. They always involve reconfiguration of technologies and systems, as they become adapted by local innovative activities within local institutional contexts. Such reconfiguration can occur as a result of entrepreneurial experimentation in (socio-) technological niches, in the process of embedding technologies in emergent socio-technical regimes, and as a result of influences from institutions and beliefs that operate at the landscape level of the socio-technical system. In applying this framework to the emergence and growth of more sustainable socio-technical systems, we are interested in how these multi-level processes of reconfiguration influence the resource and environmental quality of socio-technical systems. In the current Asian context, due to the scale of transformations, there is a unique opportunity to observe the growth and development of critical new regimes in energy, water, sanitation, mobility, housing and food. For instance, in 2002 about 45% of China's and about 35% of India's populations has access to improved sanitation (UNESCAP, 2005). Provision of sanitation for the remaining two-thirds of the population may follow a number of alternative trajectories. By acting at the niche, regime and landscape level, governments and market actors can seek to influence the resource and environmental footprints of the systems that emerge.

Questioning the convergence hypothesis: A central assumption in conventional growth theory is that convergence occurs in the general structure, rates of growth and general level of welfare in economies over the long term. In theories of economic development this is often captured in the notion of 'catch up' under which sectors in developing countries move towards a technological and productivity frontier defined by more advanced countries, broadly through a process of imitation. One implication of growth theory is that socio-technical systems will develop through the assimilation of systems that predominate in advanced countries. It follows that there will also be a convergence in the resource and environmental quality between systems operating in advanced countries and emergent systems in developing countries, a theory captured in the environmental Kuznets curve. This theory allows some improvement in resource and environmental quality through the adoption of later vintages of technology, but this effect is seen as incremental in highly resource-intensive sectors that are typically dominant in early stages of development.

The socio-technical systems perspective argues that there is greater potential for radically-different socio-technical regimes to develop, so that the implied convergence towards high resource intensity and low environmental quality development pathways can be avoided. We argue that in the interplay between innovation and institutional contexts which determine the assimilation and embedded of new socio-technical regimes, there will always be space for the emergence of alternatives with a smaller resource and environmental footprint. Convergence in economic structure, growth rates and levels of welfare can, through focused attention to the environmental quality of emerging socio-technical regimes, be decoupled from convergence in the resource and environmental footprint of development.

Recognising varieties of socio-technical regime: One can observe much variety in the composition, development and quality of socio-technical regimes in Asian contexts. There is no single model, but a multiplicity of models, defined by natural and human endowments, by historical economic, political and institutional contexts, and by the reconfiguration of technologies and practices as they fitted into emerging socio-technical regimes. For instance, whereas in north-east Asia in 2001 coal contributed 39% of final energy consumption, in south-east Asia it accounted for just 17% (UNESCAP, 2005). These varieties will have important consequences for the development of socio-technical regimes in these countries, including the emergence of radical alternatives that differ substantially from conventional models. There is, for instance, evidence of a multitude of 'sustainability experiments' in many Asian countries – including eco-cities, biofuel initiatives and sustainable forestry (see Bai et al., this issue).

Interpreting the sequencing of socio-technical regimes: One feature of economic development, borne out in work on the Environmental Kuznets Curve, is that growth generates a sequence of environmental problems (first at the local scale, later regional and finally global) to which adaptive responses are made in developing countries through investments in infrastructures and environmental governance. These responses can, in principle, be mapped as socio-technical transitions, each marked by the emergence and purposive shaping of new socio-technical regimes in industrial production, urban planning, transport or energy. Inherent to the process of economic (and social) development is therefore a sequence of socio-technical transformations. An important feature of development in Asian contexts is that this sequence of transformations may be occurring earlier and more contemporaneously. The historical evidence is that developments of socio-technical regimes are already being significantly influenced by adaptations towards environmental and sustainability goals.

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In summary, the systems innovation framework appears to offer a new way of viewing processes of economic development that focuses on formation and reconfiguration of socio-technical regimes. We deem these regimes, which are structural and long-term features of economies, to be critical in determining the resource intensity and environmental footprint of national and regional economies. Understanding how they emerge and become configured is therefore a central task for research, critical to policy. Systems innovation adopts a multi-level analysis stressing the interactions between niches, regimes and landscapes in the innovation and diffusion of novel socio-technical regimes – the firm is therefore no longer the main unit of analysis, but the firm in its institutional and market context. By employing a systems innovation framing, it should be possible to reach beyond the constraints of ideas about catch-up and convergence in the analysis of economic development which appear to assume that economic development will follow established and unsustainable pathways. But the central questions each of these policy makers faces are: Can Asian development pathways be reshaped to avoid convergence with the standard high resource-intensity model of high-income countries? And what can be the role of local and international technological capabilities in achieving this transition among transitions? We believe that by reframing these questions as issues about innovation in socio-technical systems, you can come a long way.

References

Asian Development Bank (2001) *Asian Environmental Outlook*, Manila: ADB.

Berkhout, F. (2002) Technological regimes, path dependency and the environment. *Global Environmental Change*, 12(1): 1-4.

Berkhout, F., A. Smith and A. Stirling (2004) Socio-technological regimes and transition contexts. In B. Elzen, F.Geels and K. Green (eds), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*, Camberley: Edward Elgar, pp

Booth, A. (1999) Initial Conditions and Miraculous Growth: Why is South Asia Different From Taiwan and South Korea? *World Development*, 27 (2), 301321

Bose, P. and D. Durkayastha (1994) Infrastructural development, spillover effects and strategic adoption of new technologies in the LDCs, *International Economic Journal*, 8(4): 1-14.

Chenery, H.B., S. Robinson, M. Syrquin (1986) *Industrialisation and Growth: a Comparative Study*, Oxford: Oxford University Press.

Conford, P. (2001) *The Origins of the Organic Movement*, Floris, Edinburgh.

Daspgupta, S., B. LaPlante, H. Wang and D. Wheeler (2002) Confronting the Environmental Kuznets Curve, *Journal of Economic Perspectives* 16(1): 147-168

Copeland, B.R. and M.S. Taylor (2004) Trade, growth and the environment. *Journal of Economic Literature*, 42(1): 7-71.

Dasgupta, S., K. Hamilton, K.D. Pandey and D. Wheeler (2006) Environment during growth: accounting for governance and vulnerability, *World Development* 24(9): 1597-1611

Dosi, G. (1988) Sources, Procedures, and Microeconomic Effects of Innovation *Journal of Economic Literature*. 26(3): 1120-1171.

Dowrick, S. and N. Gemmell (1991) Industrialisation, Catching Up and Economic Growth: A Comparative study across the world's capitalist economies, *The Economic Journal*, 101: 263-275.

Economy, E.C. (2004) *The River Runs Black: The Environmental Challenge to China's Future*. Ithaca: Cornell University Press.

Ernst, D. And L. Kim (2002) Global production networks, knowledge diffusion and local capability formation. *Research Policy* 31(8/9): 1417-1429.

Evans, P. (1995). *Embedded Autonomy: States and Industrial Transformation*. Princeton: Princeton University Press

Freeman, C. (1995) The 'national innovation system' in historical context, *Cambridge Journal of Economics* 19(1): 5-24.

Geels, F. W., (2002): Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and case study, *Research Policy* 31(8/9): 1257-1274

Geels, F.W. and J. Schot (2007) Typology of sociotechnical transition pathways, *Research Policy*. 36(3): 399-417

Gipe, P. (1995) *Wind Energy Comes of Age*. New York: John Wiley.

Graedel, T. (1994) Industrial Ecology: Definition and Implementation. In R.H. Socolow, C. Andrews, F. Berkhout and V. Thomas (eds) *Industrial Ecology and Global Change*, Cambridge: Cambridge University Press, pp 23-42.

Hekkert, M.P., R.A.A. Suurs, S.O. Negro, S. Kuhlmann and R.E.H.M. Smits (2007) Functions of innovation systems; a new approach to analysing technological change, *Technological Forecasting & Social Change* 74(4): 413-432.

Hobday, M (1995) East Asian latecomer firms: learning the technology of electronics. *World Development* 23(7): 1171-93

International Energy Agency (2007) *CO2 Emissions from Fuel Combustion 1971-2005*. Paris: OECD/IEA.

Islam, N. (1997) Income-environment relationship: How different is Asia? *Asian Development Review* 15(1): 18-51

Jacobsson, S. and A. Johnson (2000) The diffusion of renewable energy technology: an analytical framework and key issues for research, *Energy Policy* 28(9):625-640

Joskow, P.L. (1998) Restructuring, competition and regulatory reform in the U.S. electricity sector. In H-p Chao (ed) *Designing Competitive Electricity Markets*, Amsterdam: Kluwer, pp 11-33.

Kates, R., Turner, B.L., Clark, W.C., (1990) The Great Transformation. In B.L. Turner et al (eds), *Earth as Transformed by Human Action*, Cambridge: Cambridge University Press, pp 1 – 17.

Kathuria, V. (2002) Liberalisation, FDI and productivity spillovers: an analysis of Indian manufacturing firms, *Oxford Economic Papers*, 54(4): 688-718.

Kemp, R., J. Schot and R. Hoogma (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, 10(2): 175-195.

Kemp, R. and J. Rotmans (2001) The management of the co-evolution of technical, environmental and social systems. Paper presented at the *International Conference Towards Environmental Innovation Systems*, Garmisch-Partenkirchen, September.

Kim, L (1997) *From Imitation to Innovation: Dynamics of Korea's Technological Learning*. Boston: Harvard Business School Press.

Kuznets, S. (1966) *Modern Economic Growth: Rate, Structure and Spread*. Yale University Press: New Haven.

Lall, S. (1987) *Learning to industrialize*. London:Macmillan.

Lall, S. (1992) Technological capabilities and industrialisation. *World Development* 20(2): 165-186.

Lucas, R.E. (1988) On the mechanics of economic growth, *Journal of Monetary Economics* 22:3-42.

Marcotullio, P.J., E. Williams and J.D. Marshall (2005) Faster, Sooner and More Simultaneously: How recent transport and air transportation CO2 emission trends in developing countries differ from historic trends in the United States, *Journal of Environment and Development* 14:125-148

Metcalfe, J. (1995) The economic foundations of technology policy: equilibrium and evolutionary perspectives. In P. Stoneman (ed) *Handbook of Economics and Innovation and Technology Change*, Oxford: Blackwell, pp ??

Milieu- en Natuurplanbureau (MNP) (2007) China now No 1 in CO2 emissions. Viewed 28 January 2008 at: http://www.mnp.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition.html

Nelson, R. and S. Winter (1982) *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, M.A.

Nelson, R.R. and H. Pack (1999) The Asian Miracle and Modern Growth Theory. *The Economic Journal* 109(457): 416-436.

Raven, R.P.J.M. (2006) Towards alternative trajectories? Reconfigurations in the Dutch electricity regime. *Research Policy*, 35(4): 581-595.

Rip, A. and R. Kemp (1998) Technological change. In: S. Rayner and E.L. Malone (eds) *Human Choices and Climate Change, Volume 2 – Resources and technology*, Columbus, Ohio: Battelle.

Rock, M.T. and D. Angel (2005) *Industrial Transformation in the Developing World*. Oxford: Oxford University Press

Rostow, W.W. (1959) The stages of economic growth. *Economic History Review* 12(1): 1-16.

Sala-I-Martin, X. (1996) The classical approach to convergence analysis, *Economic Journal*, 106(473): 1019-1036.

Schot, J., R. Hoogma and B. Elzen (1994) Strategies for shifting technological systems: the case of the automobile system. *Futures*, 26(10): 1060-76.

Shafik, N. and S. Bandyopadhyay (1992) *Economic growth and Environmental Quality: Time Series and Cross-Country Evidence*. World Bank Policy Research Working Paper WPS 904. Washington DC: World Bank.

Sjöholm, F. (1997) *Technology Gaps and Spillovers from Direct Foreign Investment: evidence from establishment*. Working Paper No 38, The European Institute of Japanese Studies, Stockholm.

Smith, A., Stirling, A. and Berkhout, F. (2005). The governance of sustainable socio-technical
transitions: a quasi-evolutionary model. *Research Policy,* 34(10): 1491-1510.

Smith, A. (2007) Translating sustainabilities between green niches and socio-technical regimes. *Technology Analysis & Strategic Management*, 19(4): 427-450.

Solow, R. (1956) A contribution for theory of economic growth. *Quarterly Journal of Economics*, 70:65-94.

Sonnenfeld, D.A. and A. Mol (2006) Environmental reform in Asia, *Journal of Environment and Development* 15:107-111

Stern, D.I. (2004) The rise and fall of the environmental Kuznets curve, *World Development* 32(8): 1419-1439

Stigltiz, J.E. (1996) Some lessons from the East Asian miracle. *World Bank Research Observer* 20: 55-107.

Stiglitz, J.E. (2003) Globalization, technology and Asian development. *Asian Development Review* 20(2): 1-18.

Syrquin, M and Chenery, H.B. (1989) Three Decades of Industrialisation, *World Bank Economic Review*, 3 (2): 145-181

Tisdell, C. (2001) Globalisation and sustainability: environmental Kuznets curve and the WTO, *Ecological Economics* 39:185-196

United Nations (2006) *World Population Prospects: Population Projections*, New York, United Nations

United Nations Conference on Trade and Development (UNCTAD)(2007) *World Investment Report 2007: Transnational Corporations, Extractive Industries and Development*. Geneva:UNCTAD.

United Nations Economic Commission for Asia and the Pacific (UNESCAP)(2005) Stae of the Environment in Asia and the Pacific 2005.: Economic Growth and Sustainability. Bankok: UNESCAP.

Wang, Y., H. Zhou, S. Chen, R. Chen, D. Yang, L. Shi and Y. Wang (2006) *China Sustainable Development Strategy Report 2006.* Sustainable Development Strategy Study Group, Chinese Academy of Sciences, Beijing:Science Press.

World Bank (2002) *Globalization, Growth and Poverty: Building an Inclusive World Economy*. Washington D.C.

World Bank (2004) *Development Indicators*. Washington, D.C. World Bank

FIGURES

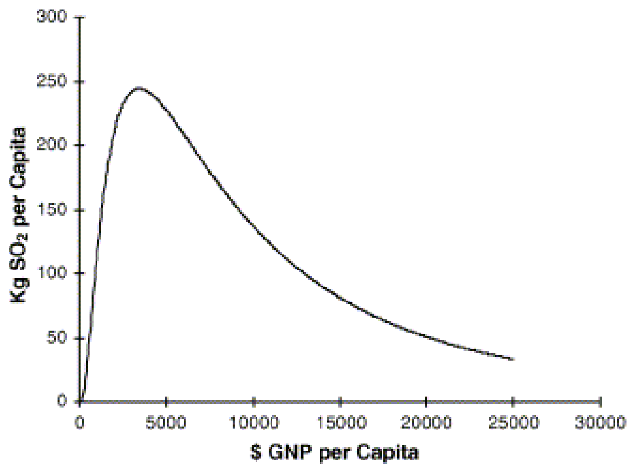

Figure 1: Environmental Kuznets curve for sulphur emissions (Source: Stern, 2004)

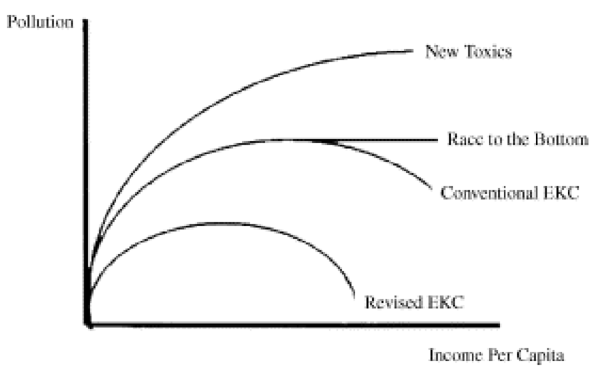

Figure 2: Varieties of Environmental Kuznets curve (Source: Stern, 2004)

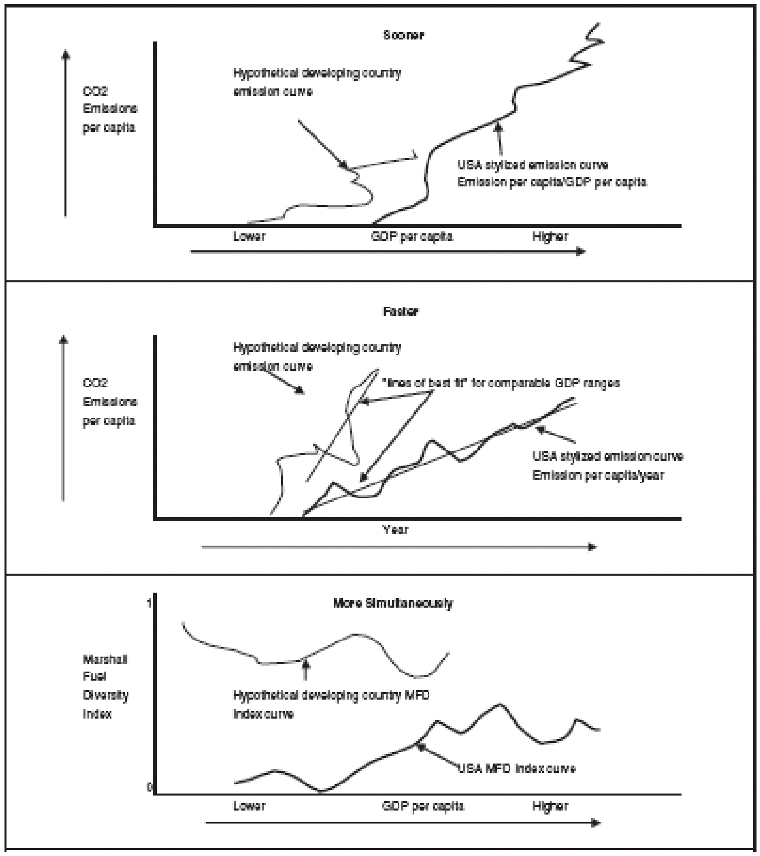

Figure 3: Sooner, faster and more simultaneous changes in environmental quality relative to income levels (source: Marcotoullio et al., 2005)